THE FCC RULES FOR THE 700MHZ AUCTION: A POTENTIAL DISASTER
Charles R. Plott
California Institute of Technology[1]
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In July 2000 the FCC issued the rules to govern the upcoming 700MHz auction. The rules are a departure from the auction architectures previously used by the FCC. Rather than all bidding only on individual licenses, the auction participants will be able to bid on combinations or packages of licenses. Several combinatorial auction processes exist in the literature and testing demonstrates that such processes have a potential for substantially increasing the efficiency of the auction. While combinatorial auction systems have been studied in various forms, indeed a particular auction architecture was developed and studied extensively for the FCC, the rules that emerged from the FCC deliberations are unlike any that have ever been implemented before.

The purpose of this note is to call attention to the fact that the particular rules developed by the FCC hold the potential for tarnishing the long history of successful auctions within the FCC. The questions posed in the pages that follow are; (i) Will the auction perform efficiently? (ii) Does the FCC have the tools to accelerate the auction or hasten its timely termination? (iii) Will the auction architecture scale up? The thesis of this paper is that the answer to all three of these fundamental questions is "no". At base the auction rules rest on an inappropriate set of principles. The principles and the intuition drawn from those principles might serve well when the auction is restricted to bids on individual items but when the bids can be on packages of items the principles simply do not apply.

The first section of this note outlines the rules. The second section lists problems that can evolve from the implementation of the rules. The third section contains observations about the sources of the problems caused by the rules and the final section suggests changes in the rules that will remove all of the problems listed.

THE FCC RULES

In this section a subset of the rules is outlined. These are the particular rules that have a direct impact on how the auction might perform. Other rules exist, which have their own impact, such as the last and best bids or tie breaking rules, but they are not addressed here. Additional issues are related to the possibility that the computer code will not accurately implement the complex rules of this auction. Experience suggests that gaps exist between the English language used to describe rules and the computer code that implement them. The differences create a foundation for surprising systemic behavior, which will not be discussed here.

The auction proceeds as a series of sealed bid rounds. In each round, bidders are allowed to tender bids based upon specific rules. The rules below govern what bids may be tendered and how they are treated by the system.

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1. Individual Package Bid Restrictions
An individual cannot place bids on more than 12 *individually definable* packages during the course of the auction.
Example 1- Individual #1 bids on the set [AB] during round t. Individual #2 places a bid on the same set, [AB], in round t+1. Both #1 and #2 have used one of their options and can bid on at most 11 other sets.

2. Round Bids and Renewed Bids (For the purposes of this discussion the concept of bids refers to previous round bids (PRB) and current round bids (CRB). Of special status are the last two rounds in which an individual submitted bids which will be called the individual's last two rounds of bids (ILTROB) as opposed to the last two rounds of the auction. Waivers or other non-bidding activities might have intervened between the last rounds in which bids were submitted by the individual and also between those rounds and the last two rounds of the auction. Clearly the ILTROB are a subset of the PRB.)

   2(a) Bids are segregated into previous round bids and current round bids. Current round bids consist of new bids placed in the current round for the first time that meet the increment requirements and renewed PRB.

   2(b) The bidder in any round can renew the highest PRB submitted on a package. This renewed bid does not need to meet any minimum bid requirement. The act of renewal will result in two bids existing in the system that are identical except that they are designated as having been submitted in different rounds. During the round of renewal the renewed bid is regarded as a current round bid and its mirror image is a PRB. A renewed PRB becomes a PRB after the current round is over but the bid still exists with a its own round date, which is different from the round date of its mirror image. Either bid can be renewed again in some subsequent round.

   2(c) For no individual round can a current round bid and a PRB simultaneously exist as provisional winners. Another way of saying this is that only bids that are current bids during the same round can simultaneously exist as provisional winners.

Example 2 - Individual #1 submits a bid in round t for [AB], which becomes a provisional winner for the round. The individual does not renew the bid for [AB] in round t+1 but submits a new bid for [CD] in round t+1 . If [CD] is to become a provisional winner then [AB] cannot be among the provisional winners.

   2(d) For each individual bidder the ILTROB together with any PRB provisional winners and current round bids are active in the system in the sense that they are candidates for becoming provisional winners in the current round. That is, a bid in ILTROB can become a provisional winner regardless of whether renewed or not and regardless of the preferences of the bidder.[2] Furthermore, these are the only candidates for becoming provisional winners. That is, a provisional winner in round t that is not an ILTROB will not be considered in round t+1 unless it emerges as a provisional winner from round t.

Example 3 – Individual #1 submits a bid in round t for [AB], which immediately becomes a provisional winner. The bid for [AB] remain a provisional winner in rounds t+1, t+2 and t+3 but it is not renewed because the individual submits new bids in those periods and does not want all of them due to budget constraints. None of the new bids become provisional winners. At the end

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[2] The reader should note this subtle feature of the rules. Whether or not a bid is automatically carried forward depends, in part, on whether or not the bidder was active.

of round t+4 the bid on [AB] is no longer a provisional winner. Unless the bid on [AB] is renewed in t+5 it will not be part of the calculations for t+5 provisional winners. If it is renewed, no activity credit will be given (see below).

3. Activity Credit
Eligibility in any round is the minimum of eligibility in the previous round and twice the activity credit in the previous round. Activity of a bidder in a round is limited to the eligibility of the bidder for that round.

   3(a). Activity credit for round t can be given only for new bids in a round (those that meet increment requirements) and for renewed provisional winners or for provisional winners resulting from the previous round computation (but not both together). That is, only these types of bids qualify for activity credit. PRB that are not provisionally winning receive no activity credit whether or not they are renewed.
   3(b). For purposes of activity computation and activity credit for round t the following family of sets and computations are identified.
       (i)   last round provisionally winning bids- resulting from round t-1 computations
       (ii)   provisionally-winning bids from round t-1that are not renewed in round t
       (iii)   all new (round t bids) and renewed (round t-1) provisionally- winning bids.

   3(c) Activity credit is based on comparisons of set(i) and the partitions[3] of set (iii). The partition of set (iii) for which the bidding units sum (the sum is over
the union of bids in the partition) to the highest weight is designated here as the *maximum weight partition*. It identifies the maximum number of bidding units of new bids and renewed previous winning bids that can become provisional winners in the current round. A bidder will receive activity credit equal to either (i) the total bidding units of previous round winners or (ii) the sum of bidding units of the new bids and renewed previous round provisional winners in the *maximum weight partition*. (Renewed bids that are not previous round provisional winners may become winners but are not part of this sum since activity credit is not given for such bids. The ILTROB that are not last round provisional winners are not part of this calculation even though they can become provisional winners in the current round.)

Example 4. Assume that each item/license is worth a single bidding unit. The individual has provisional winner [ABCD] at the end of round t-1 and the bid is not renewed. In round t the individual submits bids for [AB], [BC], [ACD], [DE], [BF] and renews a bid for [GH]
The partitions are
{[ABCD], which is a candidate because it is a provisional winner not renewed.}
{[AB][DE]};{[BC][DE]};{[ACD][BF]} The last partition ,[ACD][BF]}, is the *maximum weight partition* if all licenses have equal bidding units equal to 1, with a total of 5 as compared to 4 of the other two partitions of new bids and the weight of 4 of nonrenewed previous winners. Thus activity credit is 5. Notice that this is not the maximum number of licenses that can become provisional winners since the renewed bid [GH] must be considered and the possibilities are reflected in the partition
{[AB][DE][GH]};{[BC][DE][GH]};{[ACD][BF][GH]}. Thus, while a total of 7 licenses could simultaneously become provisional winners, the activity credit for this round is 5 (not 7) because

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[3] A partition of bids divides the bids into subsets so that (i) every license is assigned to exactly one bid in the subset and (ii) all bids the same subset can exist as provisional winners together according to the rules.

renewed bids do not get activity credit and are not part of the calculations unless they are provisional winners when renewed.

3(d). Activity used for limiting the bids that may be submitted or renewed in any round is the same as the activity credit, which is used to determine eligibility for subsequent rounds. The *maximum weight partition of new and renewed provisional winners in a round* cannot exceed the eligibility of the round. From among the new bids submitted in a round and the provisional winners renewed during the same round the total of bidding units in packages that are candidates for becoming provisional winners at the end of the round cannot exceed the eligibility of the round.

Example 5. Consider the partitions of Example 4. A bidder submitting such bids must have current round eligibility of 5 even though the number of bidding units that can simultaneously exist as provisional winners is 7.

Example 6. Renewed previously non-provisional winning bids can interact with the rules in ways that might catch a bidder by surprise. Suppose all licenses have a bidding weight of one and that bidder #1 has eligibility of one in round t. The bidder renews a non winning PSB for [ABCD]. While this package has bidding weight of 4 it can be renewed without regard to the eligibility constraint as long as the initial eligibility is not exceeded (This initial eligibility limiting calculation requires a computation similar to those described above only the partitions are different.) The bidder also places a new bid on [E], which guarantees that eligibility in round t+1 will remain at one. The renewed bid [ABCD] emerges from round t as a provisional winner but [E] does not. Now in round t+1 the provisional winning bid [ABCD] cannot be renewed because to do so would involve activity beyond the round eligibility (activity is based on renewed provisional winners and new bids). However, since renewed bids produce no activity credit (even though provisional winners) the bidder must place a new bid on one item or all eligibility would be lost the next round. So, the bidder is forced to place a bid that is competitive with its own provisionally winning bid.

4. Minimum Accepted Bid Rules
(The FCC has recently asked for comments on changes in this part of the rules. The proposed changes will make some difference to the nature of the strategies but do not change the overall implications that will be addressed in the next section.)
The Minimum Accepted Bid Requirements, which must be satisfied by any new bid are the maximum of:

   (i)   Sum of minimum opening bids (stated at the first of the auction);
   (ii)   the bidder's own previous high bid on the package plus x%.(Note that this is relative to the past bids of the bidder in question, so it can differ across different bidders.)
   (iii) lowest $ per bidding unit for any provisionally winning bid over the past five rounds multiplied by the number of bidding units in the package.

5. Maximum bids. The maximum bid on any package is nine clicks.[4] Notice that a bidder may be unable to bid enough in a single round to become a provisional winner. It could take several rounds.

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[4] A "click" is an increment in a bid price achieved by a "click" of a mouse. Each "click" increases the bid by a stated amount.

6. Auction close
The auction ends when there are two rounds with no new bids. The FCC reserves the right to impose an alternative rule for ending the auction if it is deemed necessary.

DYSFUNCTIONAL CONSEQUENCES OF THE RULES

When the rules operate as a system, properties emerge from the complexity that are not obvious when the each rule is studied independently of the others. Together the rules have several unintended consequences of the following forms.

A. The rules make available anti-competitive strategies. These are strategies that have a potential for disrupting the orderly development of the auction and its movement to the most efficient allocation. Strategies exist that allow a firm to limit competition by forging collusive arrangements. Strategies also exist that allow a firm to damage the ability of other firms to compete by constraining the bidding options of rivals and thereby reducing the competition from rivals.
B. The rules interact in a way such that competitors following their own incentives and without any competitor following some sort of anti-competitive strategy can find themselves trapped in an inefficient outcome. The rules can create traps from which competitors cannot effectively or efficiently escape from through straightforward bidding activity.
C. The rules provide the FCC with limited tools to accelerate the auction and indeed provide incentives for bidders that will slow the auction. There are only very limited tools with which to increase speed of convergence.

It is clear that a sophisticated bidder can undo or counter some of the phenomena or the problems identified in the examples below. That fact is not a basis for dismissing the examples because the counter strategies can expose the bidder to other, and perhaps more problems. Furthermore, the strategies and counter strategies are themselves a source of problems that detract from an orderly auction.

ANTI-COMPETITIVE STRATEGIES

•   Block a Specific Rival From a Package
From time to time businesses have strong preferences about the positioning of specific rivals. Suppose #1 bids on AB and in the subsequent round a new opportunity presents itself and #1 bids on CD and becomes a provisional winner on CD. Given its business plan it does not want both AB and CD together and of the two packages it strongly prefers CD[5]. Rival #2 does not

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[5] One might ask why #1 did not express a bid earlier for CD rather than AB. The answer lies in the rules, which place limits on the number of packages for which a bidder can bid. Even if #1 was not constrained by the rules, as a bidder it would not bid on all packages that it might want. Bidders must follow a strategy of bidding in relation to opportunities as they are found.

want CD but it also does not want #1 to get CD.[6] Rival #2 then immediately bids on a package, say EF that partner's conveniently with #1's bid on AB so #1's AB bid and #2's EF bid combined with other bids in the system become provisional winners. Since #1's bid on AB and #1's bid on CD were made in different periods they cannot become provisional winners together, so #1's bid on CD is not a provisional winner. Of course #1 can increase its bid on CD, which will again become a provisional winner of the current round and since [AB] was not renewed it will be dropped from the calculations making it impossible for #2 to do the same thing again. The cost to #2 for pursuing this strategy is not the cost of winning CD as #2 will not end up winning CD. This is good for #2 because he may have no value for CD at all. Under this scenario, #2 prevents #1 from winning CD by bidding on EF, which #2 may value highly. Note that although temporary blocking strategies are possible in other combinatorial mechanisms, the key that makes this one such a problem is the inability of #1 to cancel the bid on AB thereby giving #2 in inexpensive way to make #1 pay more for CD.

- Remove a Rival's Options

Suppose #1 wants AB, places a bid and becomes a provisional winner. As in the example above suppose that #2 does not want AB, having no value for the package, but does not want #1 to get the package. A strategy available to #2 is to place a bid on AB and in the same round also place a bid on CD, which #2 wants. These two bids, AB and CD are renewed or increased each round by #2 as long as #1 places bids on AB and #2 continues to drive up the price of AB until it is sufficiently high that #1 drops out. After #1 is no longer around #2 does not renew the bid on AB or the bid on CD but instead places a new, higher bid on CD. The same round #2 places bids on other packages that #2 values so CD emerges as a provisional winner along with other packages that #2 might want.[7] Since AB was not submitted the same round with the new CD bid the AB bid cannot become a provisional winner if the new CD bid does. So, #2 has successfully eliminated #1 from the competition for AB but does not have to purchase AB for itself.

- Strategy for Cancellation of Provisional Winner

The following example illustrates relatively inexpensive strategies that can avail themselves for tying up packages as provisional winners and then, in effect, canceling the provisionally winning bid. Rival #1 wants to tie up CD but places no value on that package. However, #1 does place a value on AB and places an independent value of 2 on F. In round t the bids by #1 are (AB,10) (CD,10) and the bids of other bidders are (CE,4) (DG,4)(EF,1). The provisional winners are (AB,10)(CD,10)(EF,1) for revenue of 21.

Now #1 is ready to release CD in the sense of removing itself as a provisional winner, perhaps because the firm #1 wanted to block has now moved to other packages or dropped out. The problem is to effectively cancel the bid for CD. It is done as follows. In round t+1 the bids by #1 are (AB,11)(F,3) and the provisional winners are (AB,11)(CE,4)(DG,4)(F,3) for revenue of 22. Since the new bid, (AB,11) and the bid (CD,10) were placed in different rounds they cannot win together. At a loss of 1 (because E was worth 2) #1 has, in effect, cancelled the provisionally winning bid for CD.

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[6] Such attitudes are not unusual. Different rivals have different abilities and different business models. Rival #2 might be perfectly willing to let #3 have CD because #3 not the same sort of competitive threat as #1.

[7] #2 may not have expressed bids on these other items earlier because of the budget constraint or because of eligibility constraints.

The essence of the example is to illustrate that the rules can permit costless withdrawals. Behavior like that mentioned above and below was found in the original PCS auctions and lead to a number of rule changes to keep it out of subsequent auctions. These rules invite it back.

One is tempted to reply to arguments like the ones above about one bidder being able to cancel another's bid with "Yes, but that bidder can fight back by doing the same thing. So it will be a wash." The point is that such behavior will probably happen. Thus, there could be a virtual arms race in which the bidders have to employ professional consultants to keep from getting taken advantage of, which harms small bidders who can not afford a stable of game theorists. Also, this can lead to much extraneous activity that is highly unlikely to benefit the auction.

- Collusive Mechanisms (Pre-commitments to punishments)

The existence of the either/or bid provides a vehicle for a new form of collusion not present in other auctions. The role of the rules of the auction is not dissimilar to facilitating practices found in industries from time to time. The vehicle resides in the existence of inexpensive punishment or threat strategies available to competitors.

Bidder #2 wants to influence the behavior of a competitor, bidder #1 in some way that is common knowledge to the two. Suppose bidder #1 wants some package that overlaps with the package CD. In order to exert influence, bidder #2 places a bid on a package it wants, say AB, and places a separate bid on CD in the same round. #2 may or may not value CD but #1 certainly does. Call these bids AB(t) CD(t) and assume that they become provisional winners. The next round, bidder #2 places a new, higher bid on AB, call it AB(t+1) and does not renew the two previous bids AB(t) and CD(t). The bid AB(t+1) is placed so it becomes a provisional winner. The threat to #1 is that if the behavior of #1 is not changed along the lines desired by the bidder #2 then in some round bidder #2 will renew the bids on AB(t) and on CD(t) and so AB(t+1) and CD(t) will become provisional winners. If #1 modifies behavior as desired by #2 then the renewal is never forthcoming but the threat remains. Certainly, #1 can follow a similar strategy thereby creating a mutually reinforcing structure or even a chain of such structures that can be clearly interpreted by those involved and are relatively costless to maintain since they involve no bidder buying something that is not particularly wanted.

SMALL BIDDER HAZARDS

The discussion above demonstrated how one bidder could actively work against a rival in an anti-competitive manner. Such strategies can exist in other complex auction formats, but as was shown above, the rules developed by the FCC facilitate and even encourage such strategies. The truly damaging aspect to the proposed rules, however, is that even if all of the bidders avoid attacking each other and bid according to straightforward strategies, these rules make it difficult for the bidders to achieve an efficient outcome.

- History of Bids Trap

The minimum bid requirements tie each bidder to the maximum bid that that particular bidder has placed on a package in the past. Suppose bidder #3 is bidding on ABCD against #1 who is bidding on BC and #2 who is bidding on D. #2 places a value of 10 on D and bids that amount

early in the auction in an attempt to partner with #1 so their two bids on BC and D will beat the bid on ABCD by #3. When an opportunity presents itself #2, being unsuccessful with the bid of 10 on D, places a winning bid on E, which is even more valuable than D. Suppose E is a partial substitute for D so winning it both reduces the value of D to #2 and uses up much of #2's budget. With E in hand #2 still likes D but has a value for it much lower than the original 10 that #2 bid for D. Now, later in the auction #4 places a bid on A, which become partnered with the BC bid of #1. The pair of bids, on A by #4 and on BC by #1 replace the ABCD bid of #3 in the provisional winners. This leaves D without a substantial bidder. #2, still has the highest value for D but that value has been reduced because #2 is a provisional winner on E, which is a substitute for D. Now, here is where the problem occurs. Bidder #2 placed a bid of 10 on D in the past so the minimum bid requirements prevent #2 from placing any bid on D lower than 10. However, according to the rules another bidder, especially one that has never bid on D, can bid much lower than 10. Thus, #2, the bidder with the highest value cannot place a winning bid and the item can be won by a bidder at a price lower than #2 was willing and able to pay.

- Aggressive Bidding for Tough Fitting Discouraged

The purpose of a combinatorial auction is to guide fitting of bidders into patterns that increase efficiency. A number of small bidders with appropriately defined packages can fit into a "coalition" to beat the package bid of a large bidder and promote efficiency gains when doing so. The fitting occurs through several processes of trial, error and search. In part, bidders must reveal a willingness to contribute to a coalition through high bids that reveal the potential for coordination to others. The resulting coordination requires time due to the possibility that several independent bidders must coordinate. The rules adopted by the FCC recognize the importance of having some bids remain stationary while this adjustment occurs but the rules, when considered as a system, actually discourage it.

Activity credit is given only to new bids and to provisional winners. Old bids or renewed bids that are not provisional winners receive no activity credit. Thus, a bidder who makes an aggressive bid to a potentially winning coalition will receive no activity credit for any round for which the bid is outstanding except the first. That is, a bidder who expresses near the maximum willingness to pay for a set ABC cannot let the bid sit in the system until others adjust to it because to do so would involve the loss of activity credit and the subsequent loss of any ability to make adjustments to accommodate the bids of others. The bidder must either increase the amount of the bid on ABC, which cannot be done if the bid was very aggressive, or the bidder must bid on some other set so the new bid will create activity credit.

Thus the bidder faces a difficulty. If the bid was aggressive it cannot be improved because of the values involved. The old bid cannot just remain not renewed and not competitive with any new bid because it will be removed after two rounds. If it is renewed it produces no activity credit and is also in danger of being accepted with any new bids tendered to maintain activity credit (which, together might violate the bidder's budget constraint). In part the bidder might adopt a strategy of placing a new bid and then alternatively renewing each round so the old an new never become competitive. But then activity credit will be lost because renewed bids get no credit.

Thus, a more reasonable strategy is for the bidder not to bid aggressively on the package desired. Instead, the bidder will bid only small amounts in order to leave room to improve the bid over

time and maintain the activity credit needed to make changes in the bid for ultimately fitting. But this means that the auction will be slow and that the signals for coordination opportunities that a bid broadcasts to other bidders is weak. The result hurts the small bidders.

- The coordination trap

The fact that bidders can be prohibited from bidding sufficiently high to become a provisional winner creates a potential problem. A large package bid is submitted. Small packages constituting the package have small bids. Some small bidders are at their max and others who are capable of pushing the whole set into a provisional winner cannot do so immediately because of the limitation on the maximum bid that can be submitted (9 clicks). By assumption it will take more than one round but this threatens the other small bidders with activity penalties. The coordination fails because the other bidders cannot bid more and must change their set in order to acquire activity credits.

- Reduced Flexibility for Fitting

The restriction on the number of packages on which a bidder can place bids has a potential for causing inefficiency because it is an arbitrary constraint on the manner in which fitting occurs in combinatorial auctions. The key to combinatorial auctions is to encourage bidders to adjust the packages they want so they fit with the bids of others. The system is not only a price discovery system but it is also a system that discovers the compatibility of demands. This second system of discovery is like a jigsaw puzzle in which the shapes of the individual pieces can change slightly, perhaps at a cost. Like a system of markets in which the change of the price in one market can ripple through a system of markets changing all prices to can the change of shape of one piece ripple through the system causing all others to make slight changes in shape. By limiting the individual bidders to a total of twelve packages the FCC system places an arbitrary limit on the number of shapes that any piece can assume. Since the fitting is a process of trial and error this places an arbitrary limit on the ability of bidders to find their place in the fabric of package bids.

Not only is it a limitation on the ability of a bidder to adjust to the conditions of the auction it appears to create a perverse system of incentives. The whole idea of encouraging bids early is to allow bidders to find ways to fit. This means that early in the auction the various patterns of bid packages should be explored. The problem with the FCC design is that it does not encourage early exploration of various packages for to do so limits the flexibility to adjust at the end. Thus, rather than finding appropriate fits early the system encourages exploration late.

- Negotiation Disruptions

The efficiency advantages of combinatorial auctions are typically produced by complex sequences of bidding that can be described as "negotiations" as bidders try to fit with others to either avoid confrontations they cannot win or overcome those that they can. Success translates into efficiency gains. Disruptions of this process have a potential for preventing those gains. Within the FCC rules a potential source of disruptions derives from the fact that provisional winners that are not submitted or renewed during the last two rounds of a bidders bidding are removed from the computational system the instant that they are no longer provisional winners (see example 4). A problem of negotiations disruptions exists because in a combinatorial auction bids go in and out of the provisional winners as negotiations and fitting take place that involve none of the licenses of the bids in question. Consider bids [ABC][DE][FGH] as provisional

winners for several rounds and are not renewed as the bidders try other combinations. Then, some period these bids are not among the provisional winners and because they were not renewed recently they are removed from the system. Now, the change in provisional winners was due a new bid [XY] replacing bids [VWX] and [YZ] but because the other bids are immediately removed from the system these bidders have lost their partners and thus even increasing their bids beyond the minimum bid restrictions they may not regain provisional winning status. For the negotiations to proceed smoothly the bidders on [ABC][DE][FGH] would have to renew the bids or place new bids, which might not happen for reasons discussed above because of the way that activity works under the rules.

LACK OF SPEED

- Hang on to Eligibility Without Competing

The minimum accepted bid requirements demand that a bidder only needs to beat its own bids and not those of a rival. Thus, the bidder wishing to conserve eligibility should chose a big package so it produces lots of eligibility but also has lots of competition. Since the bidder's bid need not be above the *implicit system value* of the package (the amount which could be collected from existing bids if the package alone were sold) according to the rules, the bidder should choose a package for which the system value is high. The bidder only needs to increase its bid on this package by x% each round. If its bids get sufficiently high to the *implicit system value* and is thus exposed to the possibility of becoming a provisional winner the bidder should choose another large package with high *system value* and start the process once again.

In the FCC auctions for single items, bidders attempt to maintain eligibility in a similar way. The difference here is that the minimum bid required in the FCC package bidding rules is much lower than that of the current FCC auctions for single items. In the FCC's single item auction the minimum bid requirements are above the prices of the items. New bids on these items results in a provisionally winning bid for the items (assuming no other bid on the items) and these prices will increase as any displaced bidders place bids in subsequent rounds. Under the new FCC package bidding auction rules, bids on a package do not need to be sufficiently high to become a provisional winner. In fact, the bids can even be much below the bids of other bidders on the same package. Furthermore, the aggressiveness of other bidders can have little or no impact on the minimum required bid, which is only a markup from the bidders previous bid.

Elements of this "stealth" approach are most easily seen in the single item auctions as bidders participate in bidding on popular, low priced licenses, knowing that the price will ultimately be bid up. By participating in such "run ups" bidders and switching items when there is some danger of actually winning, a bidder can conserve their eligibility and avoid placing a "legitimate bid" on licenses actually wanted. However, in single item auctions there is a strictly limited number of items on which you can do this and with each bid from any bidder the pressure to leave the strategy is increased. On the other hand, with package bidding the set of such items is greatly expanded and with the FCC package bidding rules in particular the pressure is not greatly increased by the bidding activity of others. Thus, by setting up two or three such refuges early in the auction a bidder delay any serious bidding until deep into the auction, before there is need

for abandoning the stealth strategy and bouncing pack with bids that reflect packages the bidder really wants.

- Prevent Closing

If a bidder wants to prevent the auction closing a strategy exists. It is found in the examples above in which the bidder can simply bid on different sets each round in much the same way that eligibility is preserved. It can be done without changing any provisional winners and because the number of sets on which such bidding can take place is large and because the minimum bids need not be high a bidder might be able to extend the length of the auction many rounds. If the FCC uses some other rule to close the auction then the bidder might have the grounds for contesting the basis on which the auction was closed and in a sense, keeping the auction from closing while the review process takes place.

The closing rule can also provide independent incentives to delay aggressive bidding. Since two rounds without bidding are needed to close the auction, all bidders are warned before the closing is likely to take place. The warning removes risk from bidders who are following a strategy of not revealing what their true preferences are until the preferences of other bidders have been exposed. By using strategies designed to conserve eligibility without competing a bidder can wait until the last instant, when the eligibility of other bidders might be low or exhausted as might be caused by a round of no bidding, before entering aggressive bids.

GENERAL PROBLEMS

Exactly what lies at the base of the problems listed above is hard to identify but it appears that the design of the FCC's package bidding rules reflects three inappropriate principles. These principles are drawn from theory and experience with non-combinatorial, multiple round, simultaneous auctions and from single round, sealed bid auctions. Basically, the problem is that the rules are based on principles that do not generalize to the package bidding mechanisms.

The first principle is an inappropriate focus on prices of individual items. In auctions without packaging, the prices of individual items make sense. Indeed, the rules of such auctions are based on prices of the individual items and it would be difficult to imagine the auctions operating in any other way. However, in a combinatorial auction each possible package can be viewed as an item requiring a price and there can be millions of possible packages. The error of reasoning rests on the belief that each of these packages requires a separate price and this error is compounded by the belief that such prices should be calculable from the prices of the individual items. Of course, as is well recognized, that is impossible, but the belief remains as an imagined ideal and misguides the design of rules as an attempt to get as close as possible to that imagined ideal.

Prices of packages, including the prices of isolated items, are the wrong way to think about a combinatorial bidding process. The appropriate concept is the "*implicit system value*" of a package. The *implicit system value* can take two forms. It can mean the amount it would take for a package to become a provisional winner or the meaning can involve a concept similar to the concept of the "highest bid on a package". The latter is what the package would sell for if the

bids in the system for the package and for subsets of the package were used to compute the selling price in the usual way. In single item auctions the two types of *system values* are the same. That is, if bids existed only for individual items then the *system value* of the package would be the sum of the prices of the individual items in the package in the sense that the sum would be both what it takes to win and also the "highest bid". But, in combinatorial auctions, where not all packages have bids, the two concepts are different.

In the paragraphs below a distinction will be made between the amount it takes for a bid for a package to become a provisional winner and the amount of value placed on a package by the bids in the system. The *implicit system value* used here is the latter. Notice that bids on individual items or even values on individual items are not necessary for the *system value* to be computed. Bids or even approximate prices on individual items can be useful. Approximate prices can carry important information about *implicit system value* of packages. Indeed, combinatorial mechanisms exist that are based on approximate prices of individual items. But if the information about *implicit system value* can be produced in other ways the prices on individual items are unnecessary. Certainly a combinatorial auction process should not be built on the assumptions that such prices are needed.

The *implicit system values* of all possible packages need not be listed. Comments during the rule development discussions suggest that all such values need to be computed for all packages at all times. Such values only need to be produced when needed by the bidder and can be delivered when the bidder queries the auction mechanism.

The first instance of a reliance of inappropriate principles is the focus on individual item prices as the tool for measuring minimum acceptable bids and as a tool to speed the auction. *System values* provide a natural measure of the aggressiveness of bids and can be used as the foundation of minimum acceptable bids and activity. That is, in combinatorial auctions *system values* can play exactly the same role as do the prices in the multiple round, simultaneous ascending price actions without packaging that exist around the world and with which the FCC has much experience. The proposed FCC auction makes the mistake of ignoring *system values* of packages and instead attempts to base the rules on high bids placed by individuals and on provisional winners.

The second instance of reliance on inappropriate principles is found in the belief that prices and bids should always be increasing. In single items auctions without synergies that is an appropriate principle but when synergies exist it is not. Indeed, the concept of a withdrawal used in previous FCC auctions is a recognition that bids should not be always increasing. The easiest way to see this is the case where the efficient allocation is to consider the example produced in the History of Bids Trap in the section above.

The third inappropriate principle is that full expression of preferences will facilitate a better auction. This principle produced the attempt to allow individual express an exclusive "or" in their bids. That is, the FCC has attempted to all bidders place bids of the form "either bid A or bid B but not both". Many contexts exist in which this type of expression is useful. It is especially useful when the auction involves no iterative procedures such as one round, sealed bid or single round call auctions. In such auctions bidders do not know the bids of others and cannot

adjust in the light of such information. Thus, full expression can be useful. However, in auctions in which iterations are involved the process of iteration itself allows bidders to adjust their bids in the light of the bids of others. The need for full expression does not exist and as was demonstrated above, can create a language and strategies that hamper competition rather than help.

WHAT MIGHT BE DONE?

The rules of the auction should be changed. The changes below will remove the dysfunctional strategies listed above and in doing so transform the auction into one similar to a combinatorial auction that has been studied extensively and is known to produce efficient results. It is, in essence the combinatorial auction that was designed and tested for the FCC and suggested during the comment periods. The major changes below will allow the bidders more flexibility, remove the troublesome features that accompany the attempt to allow "or" bids and base the speed of the auction on the *system values* of packages, the amount for which a package would sell given the bids in the system for the package and for its subsets. Measures of *system values* in combinatorial auctions play the same role that high bids play in simultaneous auctions.

1. Remove the requirements that bids be carried in the system for at least two rounds and replace it with a rule that says that any non provisional winner can be cancelled at any time. The FCC has expressed a fear that bidders will not leave sufficient bids in the system to allow the formation of coalitions to overcome the "threshold problem". In fact, a mountain of experience suggests that the opposite is the case. Bidders have an incentive to leave bids in the system when potentially beneficial and they do so voluntarily. However, when forced to leave unproductive bids in the system the bidders can be exposed and the danger of such exposure feeds back to influence bids in unproductive ways. The rules should leave it up to the bidders to determine the bids that are worthwhile and might be productively kept in the auction.

2. Drop limitations on the number of packages on which individuals can place bids. Replace the restriction with a rule that says that bidders can have no more than twelve package bids in the system at one time. This is a limitation dictated by the computational power of the optimization algorithm employed and there is no evidence that the original restriction as proposed by the FCC achieves any savings along this line above this one while costing significantly more in terms of flexibility. If computation capacity is not constraining then the bidders should be allowed even more bids.

3. Drop the attempt to allow "or" bids. Allowing such contingent bids makes available options and motivations that are at the root of the dysfunctional strategies. Given other changes in the rules suggested here there is no need for a distinction between renewed and new bids for the computation of activity credit and provisional winner determination. Expressions of "or" are implemented naturally due to the round nature of the auction process. On the surface one might theorize that the existence of "or" bids would speed up the auction and improve efficiency by

allowing the integration of more information into the auction with each round. Unfortunately, the analysis reviewed here suggests that the unintended consequences of the "or" bid (as implemented by the FCC) could easily decrease efficiency and slow down the auction.

4. Use *implicit system value* to determine the minimum acceptable bids. The FCC rules are inappropriately based on the bids on individual items as the measure to determine minimum acceptability. In a package bidding process the focus should be on the value of packages and not on the value of individual items. *System value* is an appropriate measure. It increases directly with the competition of bidders for the packages thereby forcing the needed compromises by bidders. It does this by allowing and encouraging bids that might have a chance to become provisional winners and preventing bids that have no chance of become provisional winners.[8]

5. Activity credit should be based on *implicit system value* and on minimum acceptable bids as defined by the rule above. Bids below *system value* should get no activity credit. Provisional winners should get full activity credit. Bids that are at or above minimum acceptable bid levels but below the level needed to become a provisional winner get partial credit. Such system of credit provides incentives for aggressive bidding while providing equal incentive for leaving bids in the system that are the foundation for coordinating. In addition it provides incentives for removing unproductive bids from the system while leaving potentially productive bids.[9]

The rule changes suggested in this section are designed to keep the system simple while staying within a class of combinatorial mechanisms that are known to work. The proposed rules are very close to those that evolved from the Wye Woods Conference. The rules are already implemented in code owned by the FCC so the pitfalls implicit in putting complex rules into code have already been avoided. The rules also lead to an auction that is scalable. As suggested, bidders can bid on as many packages as they want, limited only by eligibility and perhaps by the total number of bids they have in the system. Minimum bids are governed by *system value* in the sense that a new bid on a package must be some percentage above the *implicit system value* of the package and in this sense must always be an improvement. Activity credits are given to all bids in the system that meet the minimum bid requirements and a little more credit is given to those that actually become provisional winners. The sum of bidding units of licenses that are in at least one of the packages on which a bidder has an outstanding bid cannot exceed eligibility. Clearly, rules can be developed that involve maximum partitions, the maximum number of licenses that

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[8] The software owned by the FCC requires that new bids to be some fixed percentage above *implicit system value.* That is, any bid submitted in a round for a package should be equal to or above (1+x)(*implicit system value for the package*), where x is some percentage markup.

Preston McAfee has suggests the following method of encouraging bids on the smaller packages. For any package A (including singletons), compute ISV = the implicit system value which is the maximum bid price for the package (if a singleton, the highest bid; if a package, the maximum of the sum of the highest bids on any partition of A), and PPW = price to provisionally win, which is the amount it would take to be a provisional winner, given the current bids.
Let b be the weight of A divided by the weight of the whole set. The minimum bid on A would be (1-b)*ISV + b*PPWplus a percentage for speed. His observation is that this penalizes package bidding -- slightly. McAfee observes that it might be desirable to make b a steeper function of weight of packages, such as the square root of the weight proportion. Essentially, it says the minimum bid must be closer to provisionally winning the larger is the package. In this way, it encourages smaller bids, but still pushes them in the direction of provisionally winning.
[9] Variations of the rules exist. McAfee suggests, using the notation in the footnote above that
activity credit for a bid A = (sum of bidding units of licenses in the package)((PPW-ISV)/PPW)

might be purchased, avoid any double counting, etc., etc. but attempts to design rules that capture such supposed advantages add much complexity. In addition they can interact in ways that adds dysfunctional strategies. Finally, an important advantage of the rules proposed here is the existence of several parameters that can be used to adjust either the activity credit or the eligibility constraint should such adjustments seem necessary. The first combinatorial auction should be simple and scalable.   The complexities should be reserved for later auctions.

CLOSING REMARKS

The FCC has designed a new form of auction that is a major departure from any form of combinatorial auction that has been tested in the past. Combinatorial auctions have enormous potential for improving the FCC's auction process and producing social benefits of increased efficiency. However, to be successful the auction architecture should be reliable, or at least as reliable as is scientifically possible.

The analysis reported in this note suggests that serious, potential problems exist. The auction may work without problems. It might not crash. But, analysis suggests that the FCC is driving an unsafe vehicle. Certainly appropriate safety checks have not been made and the structure itself has not been subjected to the type of rigorous testing of other combinatorial mechanisms. Unlike previous FCC auction mechanisms, and unlike other combinatorial auction mechanisms, this one has not passed a battery of stress tests from a variety of experimenters. Initial examination here suggests that the auction itself suffers from design flaws. Hopefully, the downsides produced by the logic applied in this note will somehow be avoided and hopefully, additional pitfalls are not lurking in the extreme complexity of this particular auction process.